EXPERIENCE WITH CORE DRILLING MACHINES POWER AUGER AND ELECTRICAL RESISTIVITY ON THE PENNSYLVANIA TURNPIKE

SEPT., 1958

NO. 25

by

D.G. Shurig

&

E.J. Yoder

Joint Highway Research Project

PURDUE UNIVERSITY
LAFAYETTE INDIANA

TECHNICAL PAPER

EXPERIENCE WITH CORE DRILLING MACHINES, POWER AUGER
AND
ELECTRICAL RESISTIVITY ON THE PENNSYLVANIA TURNPIKE

TO: K. B. Woods, Director
Joint Highway Research Project

September 25, 1958

FROM: H. L. Michael, Assistant Director
Joint Highway Research Project

File: 6-14-5
Project: C36-36E

Attached is a technical paper entitled, "Experience with Core Drilling Machines, Power Auger and Electrical Resistivity on the Pennsylvania Turnpike," by D. G. Shurig and E. J. Yoder of our staff. It was presented at the Annual Meeting of the American Society for Testing Materials in June 1958 in Boston, Massachusetts.

The paper is presented for the record.

Respectfully submitted,

Harold L. Michael

Harold L. Michael, Secretary

HLM:acc

Attachment

cc: A. K. Branham
J. R. Cooper
W. L. Dolch
J. T. Hallett
F. F. Havey
G. A. Hawkins
G. A. Leonards
J. F. McLaughlin
R. D. Miles
R. E. Mills
B. H. Petty
C. E. Vogelgesang
J. L. Waling
J. E. Wilson
E. J. Yoder

Technical Paper

EXPERIENCE WITH CORE DRILLING MACHINES, POWER AUGER AND ELECTRICAL RESISTIVITY ON THE PENNSYLVANIA TURNPIKE

by

D. G. Shurig, Research Assistant
and
E. J. Yoder, Research Engineer

Joint Highway Research Project
File No: 6-14-5
Project No: C36-36E

Purdue University
Lafayette, Indiana

September 25, 1958

EXPERIENCE WITH CORE DRILLING MACHINES, POWER AUGER AND ELECTRICAL RESISTIVITY ON THE PENNSYLVANIA TURNPIKE

by

D. G. Shurig[1]

and

E. J. Yoder[2]

SYNOPSIS

This paper pertains to the use of small rotary diamond core drilling machines, power augers and electrical resistivity units when used as a team for the subsurface exploration in proposed highway cuts. Original subsurface data obtained on the Northeastern Extension of the Pennsylvania Turnpike System, extending from Philadelphia to Scranton, is compared to actual field conditions. A large number of shallow earth surface condition has been categorized into six basic groups depending on the proportion of soil, unsound rock, sound rock and attitude of the rock. Sound rock is defined relative to a stable highway cut slope. The capabilities and advantages of each machine, primarily in locating the top of sound rock in each of the six basic groups, are presented. Methods of using power augers to obtain slope design and excavation data are given. A comparison is made of the time and cost of using the core drill, power auger and electrical resistivity equipment.

1. Instructor in Engineering Geology, Purdue University; formerly Assistant Engineer-Geologist for the Pennsylvania Turnpike Commission.
2. Research Engineer, Purdue University; Consultant Soils Engineer to the Pennsylvania Turnpike Commission.

INTRODUCTION

Various features of super highways have greatly increased the quantity of subsurface data required and decreased the time available for obtaining it. Longer length, greater width, and more directness of route have increased the amount and complexity of geological and soils data involved.

Three machines that are becoming commonplace in the field of highway subsurface exploration are the small rotary core drilling machine, the power auger, and the electrical resistivity machine. The rotary core drilling machine, sometimes called a diamond core drill or simply core drill, as in this paper, was developed primarily in the mining industry. However, since rotary core drilling machines have been adapted to take soil samples as well as rock cores, they have been used extensively by geological, soils and civil engineers. In practically all big highway exploration jobs, the drilling machine is a very essential tool; but it is slow and expensive and its exclusive use is unnecessary. Therefore, the power auger and electrical resistivity, which are considerably cheaper and faster, are used either to supplement the core drill or as the primary tools.

Accurate data pertaining to proposed excavation areas are essential to efficient slope design which includes selection of the number and length of benches to provide the most efficient intervening slopes and the proper length of transition areas between sets of benches i.e. transition in a horizontal direction. With reliable data, the contractor can make a good estimate of the amount of

material that can be removed by self-loading equipment or elevating graders or by shovels without blasting and the amount of material that must be blasted.

This paper presents a comparison of drilling machines, power augers and electrical resistivity machines, and their advantages and disadvantages wher used in highway subsurface exploration. Data used for the study were accumulated from the recently completed Northeastern Extension of the Pennsylvania Turnpike System. This extension lies between Philadelphia and Scranton and traverses parts of four major physiographic provinces. The main subsurface exploration program lasted one year, January 1954 to January 1955. Total cost of the program was $364,000, which included the cost of using up to fifteen drilling machines, one power auger and one electrical resistivity machine for structure, grade and tunnel site exploration.

Comparison of the accuracy of original exploration data obtained by all three machines, especially data pertaining to the location of the top of sound rock, was made by a study of the slopes of twenty-two cuts. Cuts were examined, rather than foundation sites, because in the original exploration all three machines were used in most of these proposed excavation areas. Two cuts representing one general bedrock type or one parent soil type were examined in the field for the actual location of the top of sound rock relative to slope stability.

APPARATUS AND PROCEDURES

Most of the rotary core drilling machines used in the exploration had hydraulic swivelheads as illustrated in Figure 1. Sampling tools used with these machines were 2-in. split spoons for soil sampling and single tube core barrels with diamond bits for rock coring. The power auger was a 4-in. continuous flight auger mounted on the rear of a jeep truck. Power was supplied by the jeep motor through a power take-off. The rock cutter-head was fitted with six replaceable hard steel bits. This equipment is shown in Figure 2. The electrical resistivity apparatus was the standard alternating current Gish-Rooney type.

The general cut exploration procedure was to try the auger first. If the auger was able to penetrate to grade and the cut was relatively short, approximately 500 ft. or less, and relatively shallow, about 15 ft. or shallower, no other exploration method was used. For cuts that were longer and deeper, both the auger and electrical resistivity equipment were employed. If these data indicated rock above grade, the heavier core drills were brought in to obtain rock cores. In very rugged terrain with steep slopes and with dense woods or rock boulders, only resistivity and skid mounted drill rigs were used.

Field procedure with the rotary core drilling machines was to drive a 4-in. casing with a 250 to 300 lb. hammer. Soil samples were taken just below the bottom of the casing at 5 ft. intervals and also at every change of material. A 2-in. split spoon was used

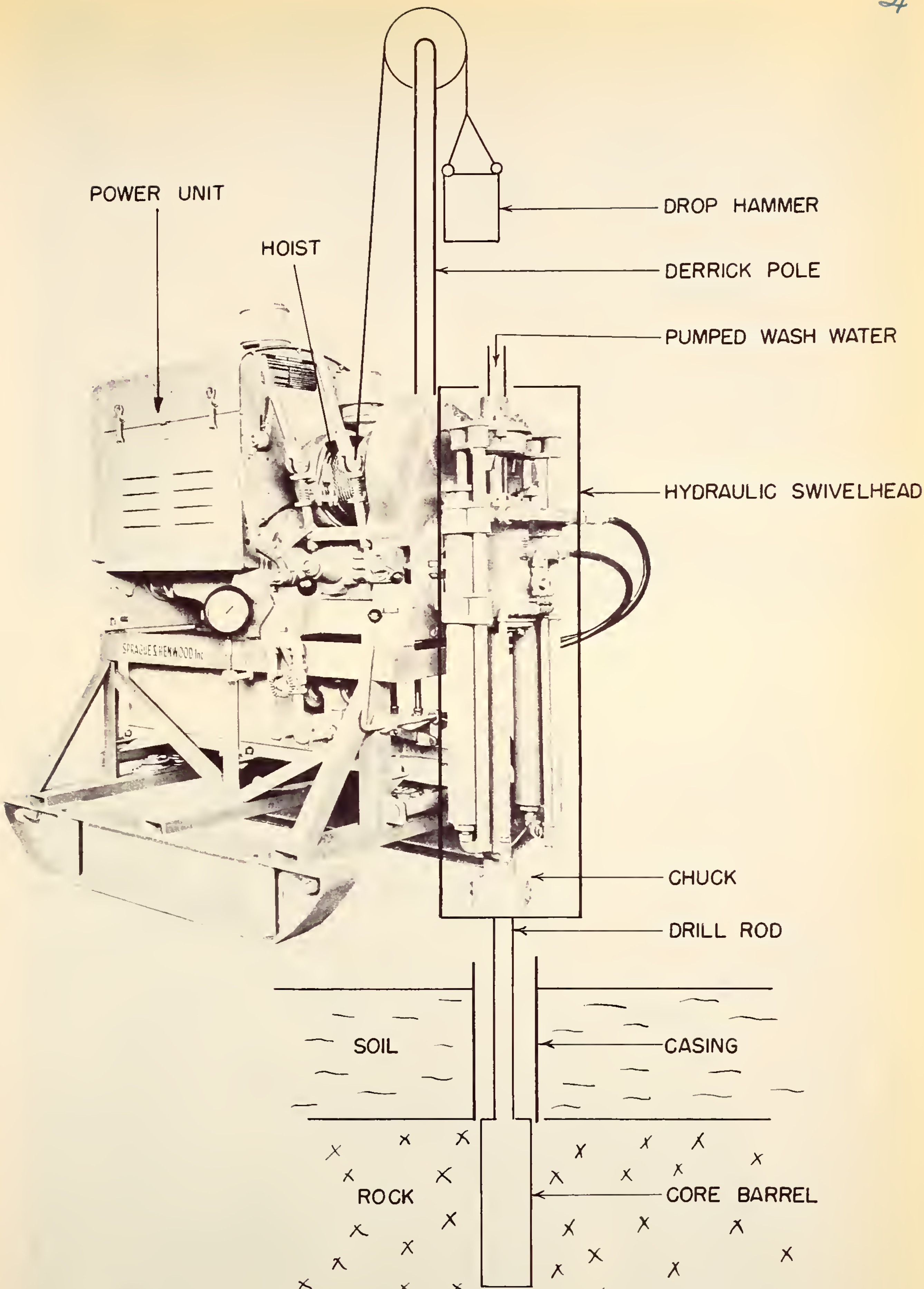

FIG. I DIAMOND CORE DRILL MACHINE

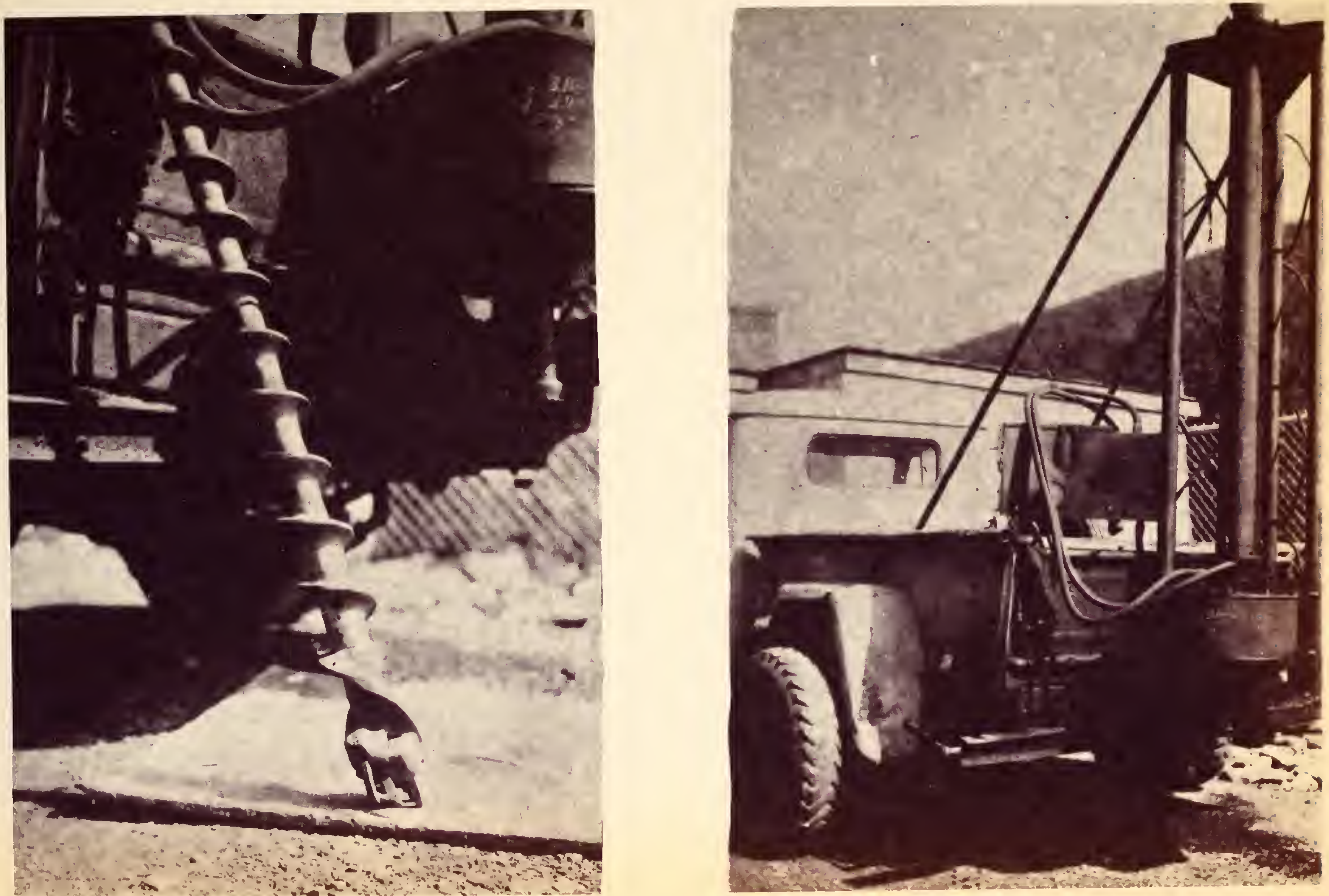

FIG. 2 A CUTTER HEAD AND POWER AUGER USED ON TURNPIKE

for both boil sampling and obtaining standard penetration test data. With refusal of the casing on firm rock, the diamond bit core barrel was used to obtain a rock core 2 1/8 in. in diameter. Holes were usually bored to a point 5 ft. below grade.

Auger field procedure was to bore to a point 3 ft. below grade or to refusal. Refusal at hard rock was indicated by violent vibration and clattering of the auger flights. Refusal in clay shales or weakly cemented sandstones and other soft rocks, occurred 1 to 3 ft. below a point at which the rate of auger penetration decreased from 1 ft. of penetration in less than a minute to 1 ft. of penetration in 1 or more minutes. Auger holes were spaced at 200 ft. intervals 40 ft. left and right of center line. This distance left and right is the location of toe of slope or the ditch line.

Resistivity data were taken at each 100 ft. survey station on center line. Depth of probe was generally 1 1/2 times the depth of cut at that station. Resistivity depth profiling was performed using the Wenner electrode configuration with 1 1/2 and 3 ft. intervals. Most often the basic curve was used for interpretation and less frequently the cummalative curve was used. All resistivity data was interpreted with previous knowledge of core drill and auger results.

PHYSIOGRAPHY AND GEOLOGY OF THE NORTHEASTERN EXTENSION OF THE PENNSYLVANIA TURNPIKE SYSTEM

The Northeastern Extension is unique in that it crosses parts of four major physiographic provinces: the Triassic Lowlands Province,

the New England-Maritime Province, the Newer or Folded Appalachian Province and the Appalachian Plateau Province. The extension crosses the province boundaries at right angles. Figure 3 shows the location, physiography and general geology (1).

Beginning at Norristown, the first 27.5 miles of turnpike cross the entire width of the Triassic Lowland Province. It is a great structural trough (graben) filled with Triassic sediments consisting mainly of red shales and siltstones and lesser amounts of friable arkosic sandstone, argillite, impure limestone and coarse conglomerate (fanglomerate). Three units, usually regarded as separate formations, Brunswick, Lockatong, and Stockton, intergrade and interfinger, and are thus facies representing partly contemporaneous deposition. The strike is essentially 90 degrees. Locally hard, weather-resistant diabase sills and dikes surrounded by baked shales, hornfels, and silicified shales, form boulder studded hills.

At milepost 27.5 the turnpike enters the New England-Maritime Province. The largest section of the province is the New England Upland Section. It has a long finger-like extension projecting into Pennsylvania called the Reading Prong. The greatest area of the prong underlying the turnpike is Precambrian Byram granite and granite gneiss which is characterized by the presence of quartz and alkali feldspar.

An abrupt 300 ft. drop in elevation at a contact of gneiss and limestone marks the point at milepost 31 where the turnpike leaves the New England-Maritime Province and starts across the Folded

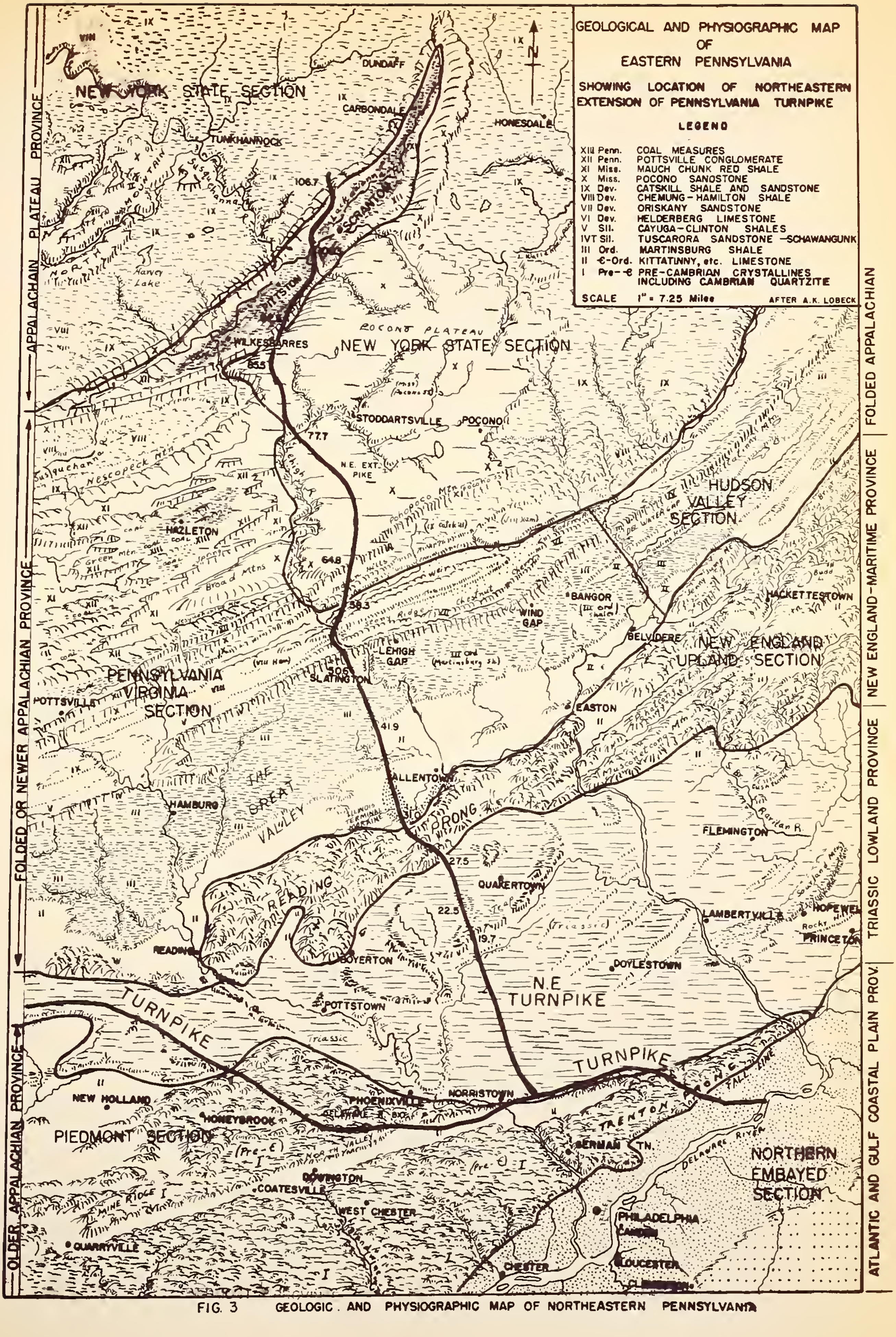

FIG. 3 GEOLOGIC AND PHYSIOGRAPHIC MAP OF NORTHEASTERN PENNSYLVANIA

Appalachian Province, better known as the Ridge and Valley Province (Fenneman). The first three quarters of the province underlying the turnpike is the famous Great Valley. Bedrock of the valley is Cambro-Ordovician limestone, dolomitic limestone, shale and slate. The turnpike crosses most of the carbonate rocks on Illinoian Terminal Glacial Moraine. The moraine forms a natural bridge over a severe solution area, so there were few sink hole problems and the morainic material afforded much low-cost excavation. The Martinsburg shale formation composes the northern half of the Great Valley and at the base of Blue Mountain, portions of the shale have been metamorphosed to slate.

A tunnel penetrates Blue Mountain which is a limb of an overturned fold, and the road then proceeds through the last eight miles of the Ridge and Valley Province to milepost 58.3. Abrupt changes in relief up to several hundred feet are the result of steeply dipping, interbedded, hard and soft formations and subsequent erosion. This 8-mi. section is actually more typical of the Province than the preceding 20 miles. A careful examination of the geological physiographic map and legend will indicate the various rock types and formations responsible for the ridges and valleys.

Next the super highway enters the Appalachian Plateau Province. While authorities agree on this name for the Province, the section is variously called the New York State Section and the Glaciated Allegheny Section. After entering the province, the road goes into a steady climb for six miles up the escarpment area of the plateau.

Elevation increases from 650 to 1600 feet. Rock is mainly a hard, fine-grained sandstone, Honesdale, and a red hard sandstone and shale of the Cherry Ridge formation.

Across the top of the plateau, the grade elevation is generally between 1600 and 1900 ft. except at the Lehigh River crossing where it dips to 1300 feet. The northern rim of the plateau is at elevation 1900 feet. From here to the Lackawanna River, the grade is skillfully maneuvered back down the north escarpment to elevation 700 feet.

The turnpike leaves the plateau near milepost 92. Here the flat-lying Devonian and Mississippian rocks of the plateau plunge steeply to a depth of 1000 ft. below the city of Scranton and form the canoe-shaped Wyoming Valley. The valley is six miles wide and extends some forty miles northeast of companion valleys of the Folded Appalachian Province.

Within the Wyoming valley, the Pottsville conglomerate and sandstone of the Pennsylvanian age form a second rim around part of the valley. Within this rim the other Pennsylvanian rocks, including the fabulous anthracite coal deposits, are folded and faulted into a complex system. The folding and faulting produced heat and pressure which completely indurated or consolidated the soft clay shales and fire clays of the Monongahela, Conemaugh and Allegheny Formations. The latter were notorious landslide producers on the Western Extension and the West Virginia Turnpike, but here

they were not troublesome. However, the coal mining operations have made the valley crossing one of the most expensive sections on the turnpike.

From the Lackawanna River in the center of the valley, the pike makes a final climb back to the top of the Appalachian Plateau.

CLASSIFICATION OF CUTS INTO SIX BASIC GROUPS

A result of a preliminary survey of the cuts selected for this study was a general definition of sound rock relative to turnpike cut slope stability. It became apparent that this definition would have to be devised in order to determine the accuracy of subsurface data. So when a detailed study of each cut slope was made, a homogeneous rock mass was considered to be sound if any one of the following conditions were satisfied:

(1) The rock required blasting for excavation;

(2) The rock resisted and withstood the efforts of a tractor-drawn rooter;

(3) The rock could stand permanently on a 3/4 to 1 or steeper slope with a minimum of ravelling.

This definition of sound rock, along with Terzaghis definition of soil, automatically set the limits or boundaries of unsound rock. Terzaghi defines soil for civil engineering purposes as a natural aggregate of mineral grains that can be separated by such gentle mechanical means as agitation in water (2).

Using the above definitions or limits, a system of classifying the cuts was devised. The basis of the classification depended upon the relative proportions of: (a) soil, (b) unsound usually highly weathered rock, (c) sound rock and also on the structure of the exposed sound rock mass. Upon applying the classification system, it was found that all the cuts in this particular turnpike extension could be divided into six basic groups. These groups are described below and they are used to explain the accuracy of the core drill, auger, and resistivity tests. The groups, illustrated in Figure 4, also portray shallow earth surface conditions with which the civil engineer works.

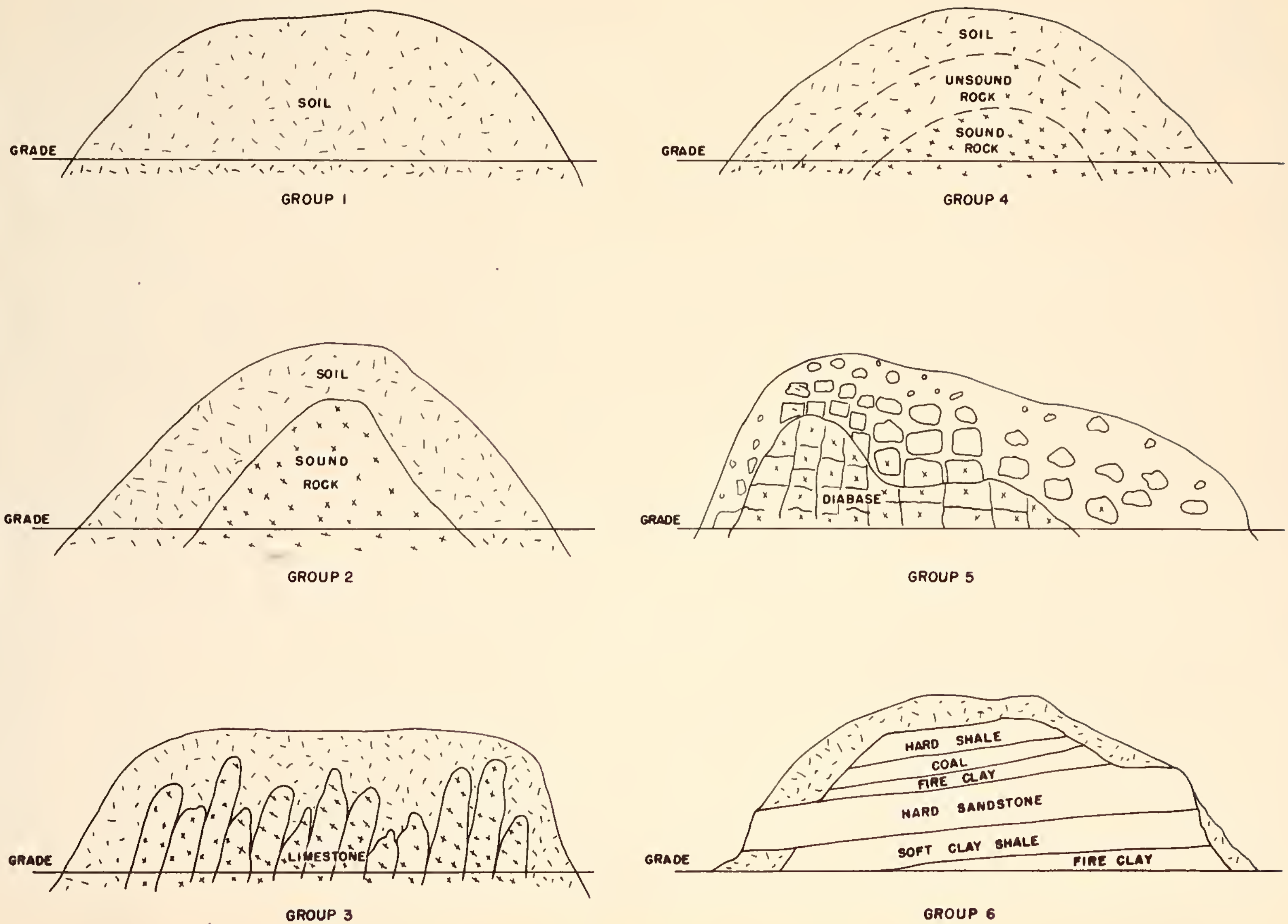

FIG. 4 SIX SHALLOW EARTH SURFACE CONDITIONS

13

Group 1, cuts containing essentially all residual or transported soils.

Group 2, cuts containing primarily soil and sound rock with a negligible thickness of unsound rock, less than 3 or 4 ft., and in which the top of sound rock is relatively regular or smooth. In these cuts the rock structure is not important as the weathering resistance of all the strata is fairly uniform. This condition can often be found over various types of strata of fairly uniform hardness or resistance. In contrast to group 1, this group also includes many cuts which contain essentially all sound rock.

Group 3, cuts containing primarily soil and sound rock with a negligible thickness of unsound rock but in which the top of sound rock is irregular or saw-toothed. In this group the dip of the rock becomes important particularly as the dip becomes steeper and as the interbedded hard and soft strata become differentially weathered. This condition was typified on the turnpike by vertically dipping, interbedded, argillaceous and siliceous, dolomitic limestone.

Group 4, cuts characterized by three-layered system type, composed of a layer of soil, a relatively thick layer of unsound rock, usually ranging from highly weathered to weathered, and a layer of sound rock. These soil and rock zones are more or less parallel to the surface, or generally horizontal, and intergrade imperceptably into each other. Dip in these cuts is not effective. Clay shales usually weather in this manner.

Group 5, cuts in boulders. In very general terms this type might consist of 50 per cent boulders, 25 per cent soil, and 25

per cent sound rock or some other percentages with the per cent of boulders being relatively high. On the turnpike this situation was found in diabase cuts. Here, cooling has produced a set of horizontal and vertical tension fractures which have divided the fresh rock mass into rectangular blocks.

Group 6, deep cuts with a layer of soil and alternate layers of sound and unsound rock. Dip of these rocks is most often relatively flat as movement frequently indurates the softer beds. Good examples are found in the soft coal regions where interbedding might include sandstones, soft clay shales, coal and fire clays.

EXAMPLES OF EXPLORATION DATA
AND
FIELD CONDITIONS OF EACH CUT GROUP

A detailed study was made of both slopes of twenty-two cuts. In this manner a vivid picture of actual soil and rock conditions was obtained. The type and depth of rock weathering was studied as well as the structure and attitude of the rock. Excavation methods and problems were learned and the final slope design was analyzed. Representative cuts are illustrated in Figures 5, 6, 7, 8 and 9. The data that were plotted in these figures are described in the following paragraphs.

A primary object of the investigation was to determine the accuracy of each machine in locating the top of sound rock. To accomplish this, depth to sound rock was measured on both slopes of a cut at each station with a hand level. By plotting this field information on the respective cross-sections, the approximate depth to sound rock at center line could be interpolated. These latter

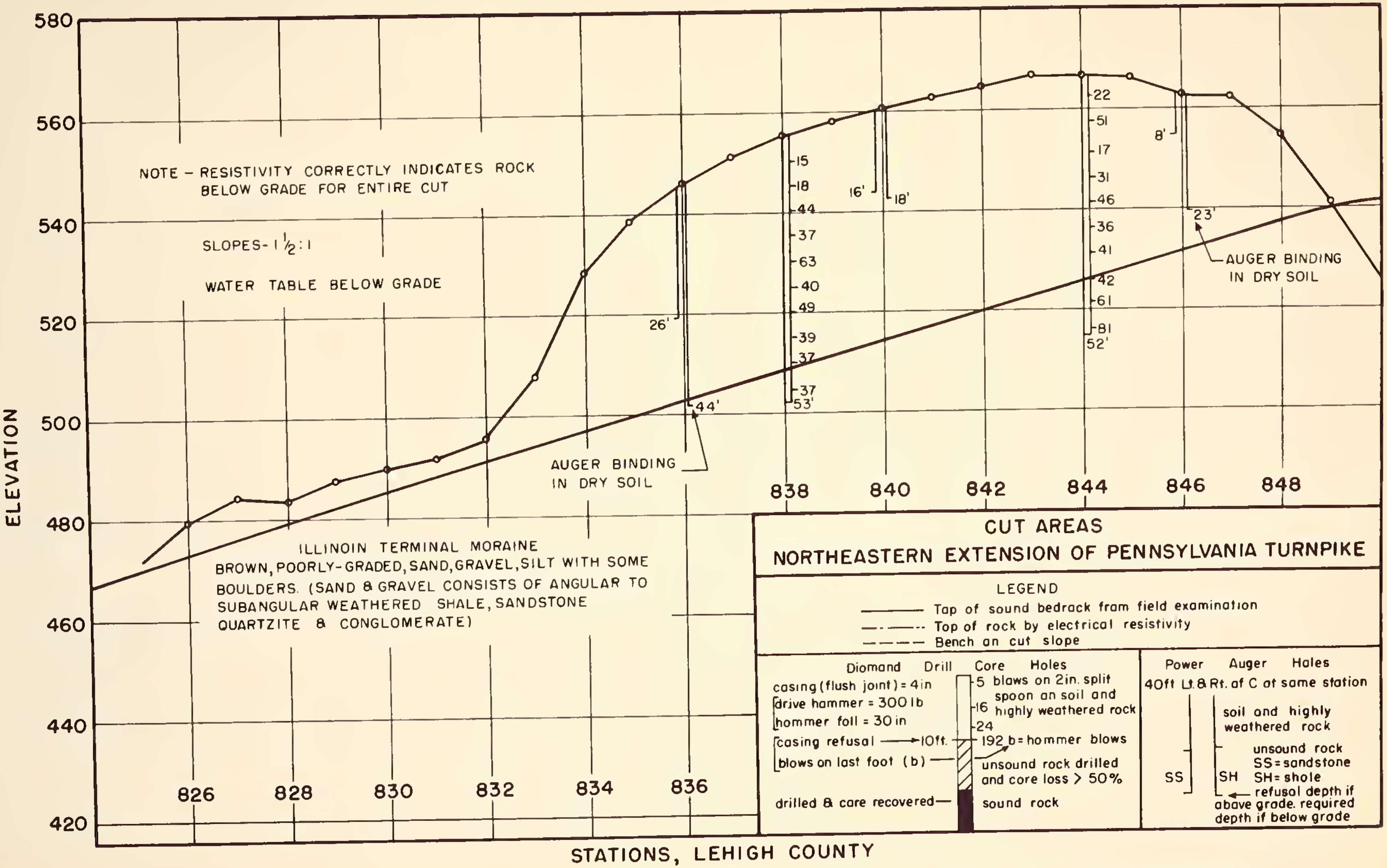

FIG. 5 EXAMPLE OF GROUP I - SHALLOW EARTH SURFACE CONDITIONS

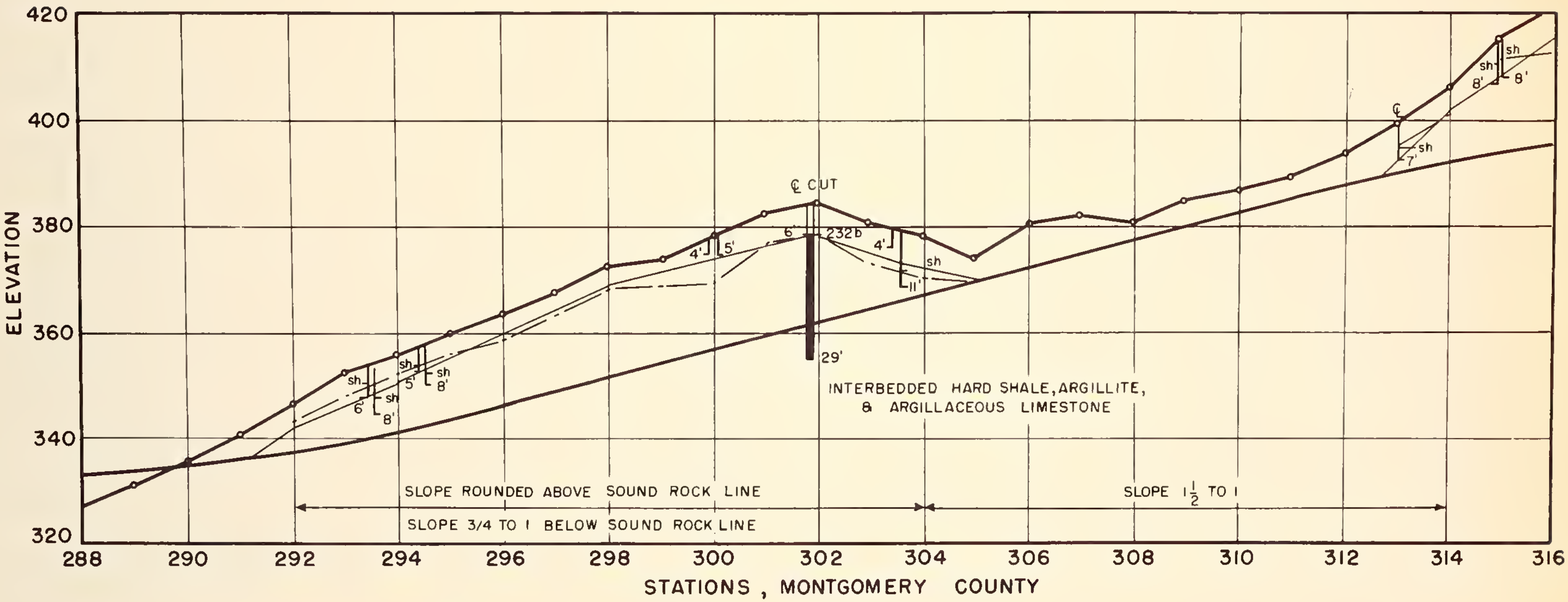

FIG. 6 EXAMPLE OF GROUP 2-SHALLOW EARTH SURFACE CONDITIONS

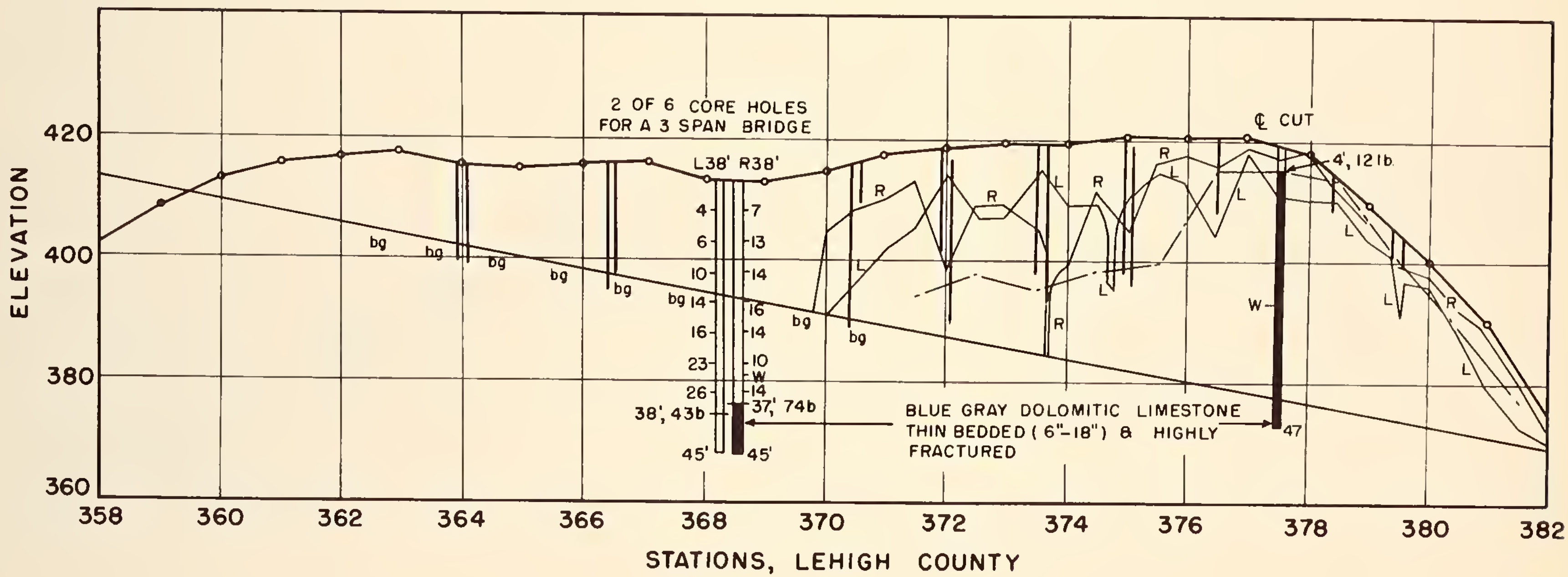

FIG. 7 EXAMPLE OF GROUP 3-SHALLOW EARTH SURFACE CONDITIONS

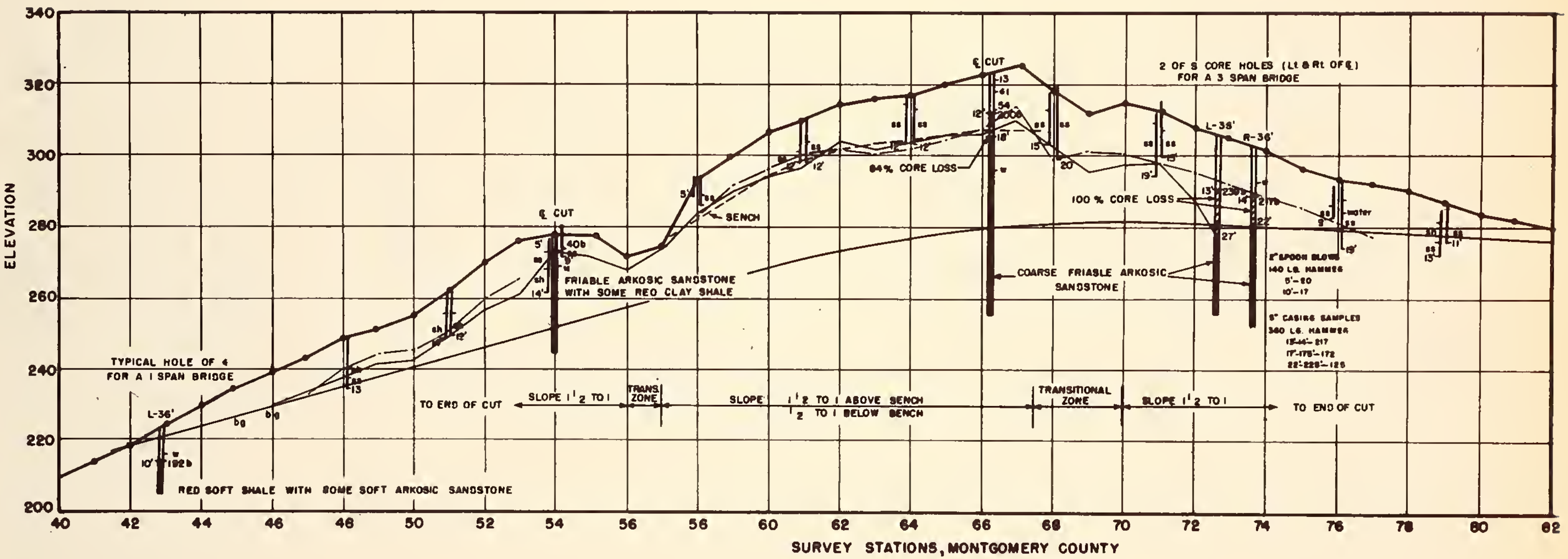

FIG. 8 EXAMPLE OF GROUP 4- SHALLOW EARTH SURFACE CONDITIONS

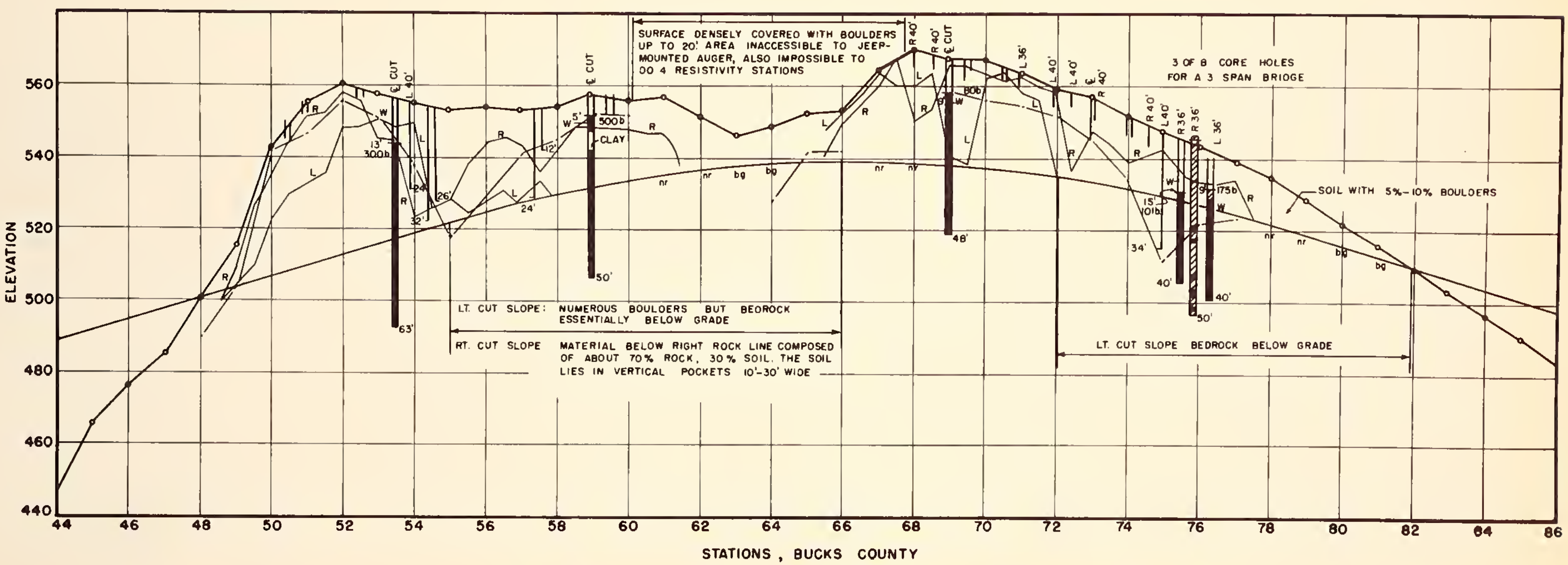

FIG. 9 EXAMPLE OF GROUP 5-SHALLOW EARTH SURFACE CONDITIONS

depth-points were in turn plotted on a grade profile, to show the top of sound rock profile along center line. Where the top of sound rock was irregular, the rock profiles for both right and left slopes were drawn in order to emphasize this erratic condition.

Exploration information obtained with the core drilling machines and plotted was: the depth of casing refusal and the number of blows at casing refusal, the location and blows of each standard penetration test, portions of hole depth where core loss was greater than 50 per cent and where core loss was less than 50 per cent, position of the water table and the type of bedrock. The depth and location of each auger hole is shown as a solid vertical line. The type of soft rock augered is also indicated. At each survey station, a dot is used to mark the top of rock below center line as estimated by interpretation of the electrical resistivity data. Each dot is connected by a dashed line. Also shown on the grade profile sections is the final slope design used for each particular cut studied.

Because of space limitations, only one representative cut of each of the above groups can be presented. It should be borne in mind that an excavation area can be composed of the conditions of one group or a combination of two or more of the basic groups.

Group 1

A deep cut in Illinoian terminal moraine, located in the Great Valley south of Blue Mountain, is presented in figure 5 to represent the conditions of Group 1. It was also selected to show slight difficulties that were encountered in connection with power augering

in deep, dry, bouldery sand soils due to binding.

The figure shows the length and depth of the cut, location of borings and position of the water table which is indicated to be below grade. Both the rotary and resistivity equipment were completely accurate in indicating all sound rock below grade. The auger, however, had trouble with an apparent binding condition caused by the unstable dry granular soil. As the soil was flighted to the surface, the caving walls tended to squeeze it and stop rotation of the auger. Binding became apparent around 20 ft. Logs for the shallow auger holes state that refusal was probably due to a boulder. Because the geology of the cut was so obvious, and because of some jeep engine difficulties, only a fast survey of this particular cut was made with the auger, and no additional attempts were made to bypass the boulders.

Group 2

Figure 6 illustrates a cut in which the rock is dark grey to black shale and argillite with a lesser amount of impure sandstone and limestone. Strike is 90 deg. to center line and the dip is 15 deg. north. The soil and weathered rock cover are very thin with the transition into sound rock being relatively fast. Because of the thin bedding and a gradation of material from one bed to another, it is impossible to show the location of each rock type in the drawing. However, above the harder and more brittle rock types is a layer of hard fragments and slabs. This loose rock at times stopped the auger 1 to 3 ft. above sound rock. In the softer,

more shaly material, the auger penetrated 1 to 2 ft. into sound rock. Auger holes near the core hole at station 302 met refusal corresponding to casing refusal in the core hole. The two refusal depths marked the top of sound rock. At station 300, where auger and resistivity tests vary, the auger was more nearly correct.

In this cut both auger and resistivity data are considered accurate from a practical viewpoint. An advantage of the resistivity probing over the auger boring is illustrated between stations 295 and 300. Here the owner of a landscaped plot did not want the truck-mounted auger to enter, but he would permit the resistivity crew to work as the latter would cause absolutely no property damage.

Because of the depth, and consistency of auger depth, and because the area between stations 305 and 313 was relatively low, it was believed that the soil was deeper than grade and no subsurface exploration was made. Field examination proved the assumption correct. The cut north of station 316 was similar to the lower part shown so it is not presented.

Group 3

Figure 7 shows a cut in blue grey, thin bedded, highly fractured and differentially weathered argillaceous and siliceous dolomitic limestone. Strike is 90 deg. to center line, dip is 90 deg. and soils of this cut are moderately plastic silty clays.

Between stations 359 and 370, all subsurface data were 100 per cent accurate. All bedrock was below grade. From station 370 to the end of the cut, the top of the rock surface was extremely irregular because of differential weathering in the vertically dipping beds.

There were numberous deep vertical clay seams from 1 or 2 ft. to 30 ft. wide. In Fig. 7, only a few of the larger ones are shown. Many of the others were too small to show because of the scale of the drawing. It can be seen that some of the auger borings penetrated some of these undrawn vertical seams. The auger is suspended from a universal joint, making it free to glance in any direction and so the auger frequently found its way down some of these vertical clay seams.

In the first portion of the rock area, the auger and resistivity tests indicated the rock to be about 10 ft. too low. Actual mapping of the top of sound rock during grading operations was very difficult because of much fracturing. Considering this and the fact that the resident engineer informed the writer that the first few feet of rock were removed with a shovel, without blasting, it can be said that both the auger and resistivity tests did very well.

Group 4

The cut shown in Fig. 8 represents gradationally weathered bedrock. Rock in this cut is chiefly yellow, coarse grained, friable, thin bedded and fractured arkosic sandstone with some soft argillaceous shale and sandstone. Strike is 90 deg. to center line and dip is 10 deg. to 30 deg. north. Soil depth ranges from 2 to 4 feet. A middle layer, 10 to 15 ft. thick, is composed of weathered rock. The main mass of sound bedrock is essentially a friable arkosic sandstone.

Though the penetration blows, at the bridge site station 73, indicate an allowable pressure of 5 or 6 tons per sq. ft., 13 to 14 ft. below the ground surface, the high core loss from this depth to grade strongly indicated slope instability for slopes of 3/4 to 1

and steeper. The material in the vicinity of these two core borings was removed by power shovel without previous blasting. Thus, as shown in Fig. 8, the resistivity test, in this vicinity, shows a rock line that is too high for the top of sound rock as defined for a cut slope. However, throughout the remainder of the cut, the auger and resistivity tests are essentially 100 per cent accurate.

It should be noted that the auger holes, centering around the core hole at station 66, have penetrated to the elevation where the core loss changes from greater than 50 per cent to less than 50 per cent. A similar relation is seen between core borings for stations 72 to 74 and the auger holes at station 76. The consistency of penetration depth and the smoothness of a line drawn through the bottom point of the auger holes gives some inherent evidence of the dependability of the auger tests.

As mentioned earlier, all core drill and auger data were previously available to aid in the interpretation of the electrical data. Since there was considerable corrolation data for the interpretations, this particular cut example is primarily a test of the capacities of the power auger and secondarily a test of the capabilities of the electrical resistivity. Another reason for presenting this cut is that it illustrates the detailed slope design, lower part of Fig. 8, that can be obtained when the core drill, power auger, and electrical equipment are used as a team.

Group 5

A boulder type cut is illustrated in Fig. 9. Here the rocks are dark grey, massive, extremely hard diabase. This diabase is

a sill that has been exhumed by erosion.

Tension cracks formed by cooling of the original molten mass, produced a fairly well developed joint system which in turn left the rock as a mass of more or less rectangular blocks. Where cooling was slow, the blocks measure about 30 ft. across and the texture is coarse grained. Where cooling was fast, the tension joints have shattered the rock and the texture is fine. Often, where the diabase is shattered, weathering is deep. This probably results from the greater total surface area exposed by the smaller pieces. Because of pronounced irregularity in the top of the sound rock, the top of rock was determined on both the left and right cut slopes and plotted as such rather than being interpolated to a single profile along center line as in most previous examples.

Diabase ridges are usually densely wooded and boulder strewn. These conditions were unfavorable for the jeep mounted power auger, but not for the resistivity equipment. The auger crew was instructed to bore wherever possible with the idea of keeping longitudinal spacing near 100 ft. and lateral spacing near to 40 ft. left and 40 ft. right. Seventeen stations were completely missed by the auger and a few other stations lacked test holes on either the left or right side. The resistivity equipment, however, missed only six of the stations. These are marked "nr" near the grade line.

On nearly every auger log of borings that failed to reach proposed depth of grade, the following note was placed, "Refusal may be a boulder and not bedrock; see core boring and resistivity data."

Thus auger data alone would have been very unreliable. Even for holes that reached grade, the auger might have penetrated very narrow clay seams. The use of the combined auger and core boring data as a guide increased the apparent accuracy of the resistivity data. However, the reliability of the auger and resistivity in this cut were highly variable. In some cases, the auger and resistivity were in error up to 10 or 20 feet.

Group 6

The Group 6 type, interbedded sound and unsound rock, was very rare on the Northeastern Extension. The few cuts in which the core drilling indicated this condition existed had not yet been excavated at the time of the field study. However, interbedding of hard and soft strata was quite common on the Western Extension, near Pittsburg, in the soft coal regions. The soft beds are the fire clays and clay shales and the harder ones are sandstones, limestones, hard shales and siltstones.

EVALUATION AND COMPARISON OF THE ACCURACY AND EFFICIENCY OF EACH MACHINE OPERATING IN EACH BASIC CUT GROUP

The rotary core drill machine located the top of sound rock by casing refusal in over 75 per cent of the borings. For the remainder of the borings, the top of sound rock was located below the bottom of the casing at a point where the core recovery became and stayed greater than 50 per cent, plus or minus 10 per cent. In comparison tothe power auger and electrical resistivity, the rotary core drill machine, with various auxiliary soil and rock

sampling devices, produced the most accurate and complete data in each of the six groups. Therefore, the bulk of the remaining discussion under this heading will be devoted to a comparison of auger and resistivity results.

In this study the accuracy of resistivity test results was excellent for cut groups 1 and 2, that is, where rock was below grade, very near the surface, or where there was a relatively sharp contact between soil and sound rock. Auger results for these same groups were also excellent. When rock is below grade, the exact depth is not required. This situation naturally tends to increase the resistivity and auger effectiveness and accuracy.

In the case of group 3, thin bedded and differentially weathered limestone, steeply dipping, resistivity accuracy began to decrease. While the resistivity indicated an average depth to sound rock for a relatively large horizontal area, the auger indicated the depth to sound rock for a pinpoint location. Thus the auger showed that the saw-tooth condition existed with a magnitude of differential weathering up to 20 feet. In some other cuts, some clay seams only a few feet wide ran to depths of 40 ft. below the top of adjacent rock strata. The resistivity data alone can not show that these thin vertical seams are present, but the auger can. During excavation, much blasting energy can be lost through seams. The data indicate the preference of the auger to the resistivity for cut exploratory work in rock of this type. However, the longi-

tudinal interval, between auger holes left and right of center line, should be reduced to about 50 ft. and the number of diamond drill core borings should be increased. From a practical standpoint, as shown in describing the Group 3 example, both the auger and resistivity methods did very well.

In group 4, the three-layered type in which soil grades slowly into weathered rock and then slowly into hard unweathered rock, the auger was at its best in locating the top of sound rock. It has been noted repeatedly in this study that auger refusal very closely matched casing refusal or else the point where core recovery became greater than 50 per cent. In other words, auger refusal, in certain homogeneous and gradationally weathered formations, accurately located the top of sound rock for a stable slope of 3/4 to 1 or steeper.

The action of a power auger with a rock cutter-head can be compared to that of a tractor-drawn rooter used in construction. Numerous checks with resident engineers have shown that auger refusal, rooter refusal, top of sound rock, and the start of required blasting all were very close to the same point in the group 4 cuts.

Though the group 4 example shows the electrical data to be quite accurate, except near the right end of the cut Fig. 8, it must be remembered that considerable core drill and auger data was previously available to help in making the interpretations of the resistivity graphs. It is common knowledge among geophysicists that resistivity graphs all too frequently do not break distinctly at

sound rock in these gradationally weathered formations. It is because of these indistinct breaks in the curve and the uncertainty of the interpretation that the writers perfer to use power augers in these types of materials.

For group 5, the boulder type of cuts, neither the auger or the resistivity test, alone, is satisfactory as a supplementary tool to the core drilling machine. Suggested exploration procedures are: (1) use only drilling machines and bore a relatively large number of holes; (2) bore a smaller number of holes with the drilling machines and approximately double the number of supplementary auger borings and resistivity soundings. The latter method was used in exploration of diabase cuts on the turnpike.

Group 6 cuts with interbedded sound and unsound rock had not yet been excavated on the Northeastern Extension at the time of the field study. However, the results of studies of electrical resistivity surveys over similar conditions is fundamental. Frequently the electrical resistivity graphs do not show the unsound layers simply because the data for each succeeding layer with depth is influenced by the overlying layers. In other words, the thinner and deeper an unsound layer, the less chance it has of showing on the resistivity plot.

The power auger is even less adequate in these cuts because refusal is attained at the top of the first sound layer.

Since the dip involving these sediments is most often relatively flat and the strata boundaries frequently well defined, several core holes in a cut of 1000 ft. would probably suffice. However, it would be necessary to concentrate on high core recovery by using double tube core barrels producing a core of at least 2 1/8 in. in diameter. It would also be advisable to split each cored sample and subject parts of it to wetting and drying, freezing and thawing, or other tests.

Power Augers

Even though no commercial power auger has been manufactured strictly for civil engineering subsurface exploration purposes, the commonly used power augers of today afford a number of significant advantages over the hand auger. Hand augering is hard labor and in dry, or frozen, or gravelly soils, or soft rock, hand augering is nearly impossible. The power auger is fast and even the above-mentioned materials are easily penetrated to relatively deep depths. In soil exploration, the power augers have a number of advantages over the rotary drilling machine. The former does not require the use of wash water and so all the complications of the use of wash water is unnecessary. Set-up time, or time to put the auger into operation after reaching the site, is only a matter of seconds or minutes. They are not hindered by the slow and difficult task of driving and pulling casing. Power augers are comparatively simple to operate and require only a nominal amount of manual labor.

Fig. 10A shows how a single flight auger can be used, to obtain a representative sample of a relatively thin soil layer from a depth which can be determined within about six inches. If a larger diameter cutter-head is used, an accessible test pit can be bored permitting visual inspection and the removal of undisturbed samples from the wall of the hole. The main disadvantages are that only cohesive soils above the water table can be sampled; otherwise, the hole might cave. A second disadvantage is that the depth of sampling is limited to about 20 ft. due to the length of the Kelly bar.

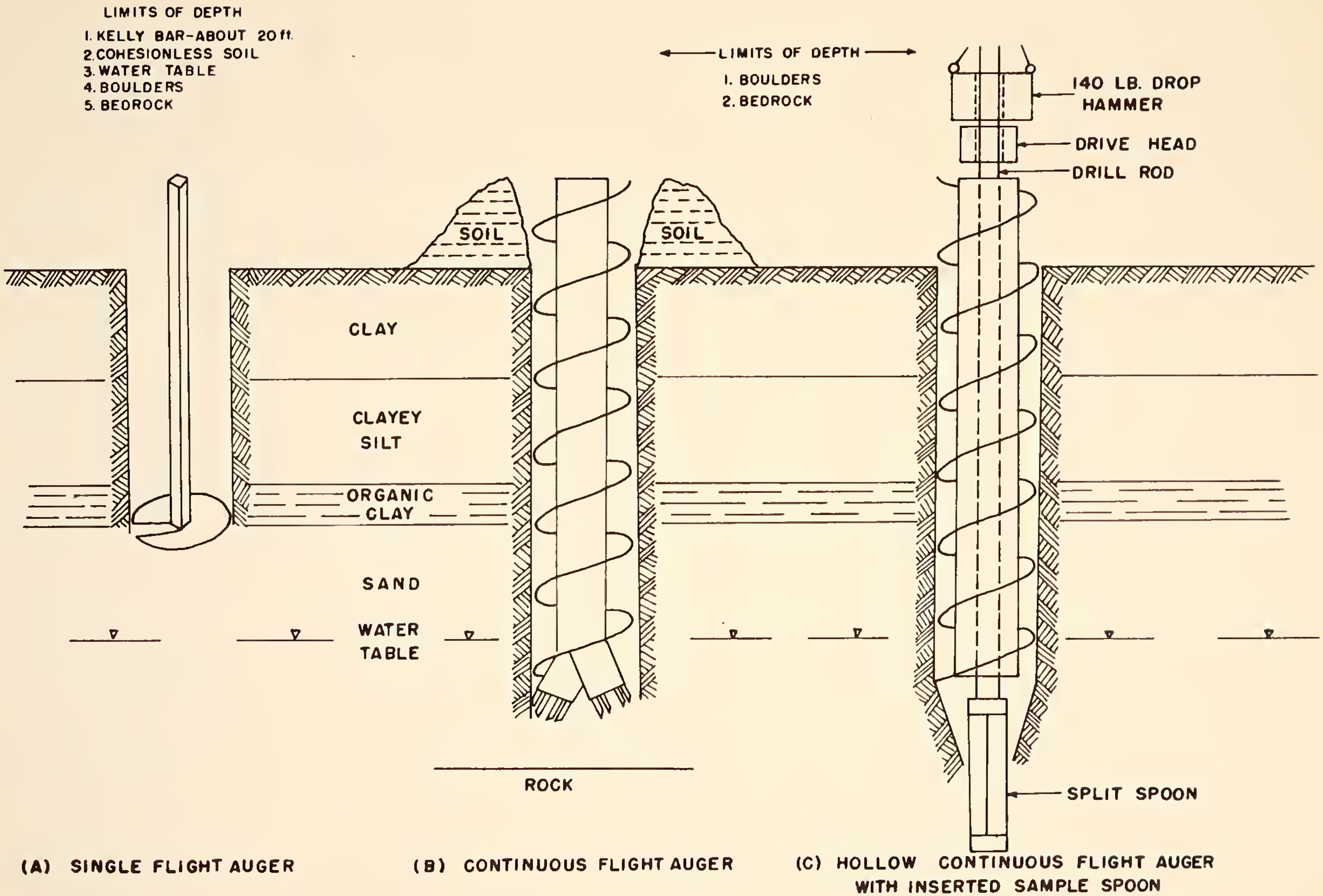

FIG. 10 POWER AUGER TOOLS

Advantages of the continous flight auger, Fig. 10B, for exploratory work is that it can penetrate to great depths in most types of soil, both cohesive and noncohesive. The main disadvantages are (1) as penetration increases, it becomes more difficult to determine the exact depth from which the soil discharged at the surface was actually excavated, and there can be some degree of mixing of the soil from various strata resulting in a non-representative sample. These two disadvantages suggest that the continuous flight auger be used in deep homogeneous soils.

The hollow stem continuous flight auger, Fig. 10C, which is fitted with a plug-point when the hole is being advanced, is one of the few power auger tools originally developed for exploration work. Used with various sampling devices, representative samples from exact known depths can be obtained from cohesive and noncohesive soils above or below the water table.

Beside these standards and special power auger tools, many of the standard soil sampling tools and soil testers can be adapted to the augers, and ingenuity and resourcefulness as to techniques increase their flexibility and usefulness.

Relative Time Requirements

The following example is given to show a comparison of the speed of operation of the resistivity unit, drilling machine and power auger. If the electrical equipment is on location, but not set up for a test, a four to six man crew can make a complete 40 ft.

sounding in slightly less than a half hour. Soil and rock conditions do not influence the amount of time required for a field run. By way of comparing this speed or rate to that of a diamond core drilling machine and power auger, it is assumed that bedrock is 30 ft. deep and that a stream, as a supply of wash water, is several hundred feet from the site of the hole. To unload and load a diamond rill rig, casing, drill rods, water pump, water hose, drop hammers, etc., from the truck and set up all the equipment, including the laying of a water hose to the stream, and then taking six disturbed soil samples and 10 ft. of rock core, it would take an experienced crew of two a full day. If a continuous flight power auger was used, and no boulders were encountered, refusal would be at a depth of 30 ft. A two man crew on the auger could take six disturbed samples in slightly over a half hour. It can be noted that time difference for auger and resistivity is not great. However, in rugged terrain slow maneuverability of the truck-mounted auger cannot begin to compete with the fast portability of the resistivity equipment.

Relative Costs

The bulk of the subsurface investigations were performed in 1954. Sampling with the use of diamond drill core boring machines was all contract work. The field procedure is given under the heading "Apparatus and Procedures." The following costs were for sampling by the core drill rigs. In several sections, when it was known in advance that bedrock was very deep and that no rock cores would be required, the unit sampling price was $3 a foot. Two-inch

split spoon samples were taken at 5 ft. intervals and change of material. However, most holes sites required both soil sampling and rock coring. The core drills penetrated at least 5 to 10 ft. into bedrock, and the soil sampled as above. The unit price per foot of this combined sampling ranged from $4.20 to $7.90. The higher price was for the Pocono Mountains area where the terrain was rugged and wooded and the roads infrequent. The combined sampling for sites under water was $12 a foot. Two horizontal core holes in rock, averaging 1700 ft. a piece, were drilled for a tunnel. The unit price was $12 a foot, but there was an additional charge of $2000 for assembling and dismantling equipment at the site.

The power auger and procedures also have been previously described. The work was performed by turnpike personnel. The following costs include depreciation, operation and maintenance of the auger and jeep truck, salaries, office overhead expenses, and soil sampling supplies, but not the cost of soil testing. The data and samples obtained were: (1) a visual description of the type and depth of each different soil and loose rock encountered (2) the depth of free water, if encountered (3) the depth of auger refusal (4) an average of one 10 lb. sample and one moisture sample per hole for laboratory testing.

The total footage augered was 11,443 ft. for 967 holes, giving an average hole depth of 11.83 feet. The total cost was $23,546,

with an average cost of $2.05 per foot or approximately $24.60 per average 12-foot hole.

Several factors contributed to make this cost slightly higher than what it might have been. Work was highly scattered over the 100 mi. of center line. Secondly, the jeep truck was already six years old and worn at the start of the job. Truck repairs, for this reason, were costly both in time and money. Running the auger from the jeep engine through a power-take-off proved to be mechanically inadequate. However, the auger equipment itself was surprisingly durable and fairly low in maintenance costs.

The total number of resistivity stations sounded was 1,852, with a total footage of 67,090 feet. Thus the average probe depth at each station was 36.2 feet. The total cost was $22,908, or 34 cents per foot, or $12.36 cents per station-sounding. The cost included the geophysicist's interpretation of the depth to bedrock. Previous brushing of the center line by surveyors helped to speed the work and reduce the cost slightly.

CONCLUSION

On an extensive highway subsurface exploration project involving both soil and rock, diamond core drilling machines, power augers, and electrical resistivity units should be used as a team. Efficient performance depends on the ability of the engineer in charge to make reasonably good estimates of subsurface conditions before field sampling or testing. With a few years experience, a geological engineer, with formal training in soil mechanics, can become proficient in his predictions, especially if he makes a careful study of available literature, geologic maps, soil maps, aerial photographs, and of field surface conditions. His estimate of the type of rock, its strike and dip relative to center line, the manner and degree of rock weathering, and the type and condition of the residual soil or transported soil, should be close to the materials and conditions actually observed in the samples.

In exploration work on the Northeastern Extension of the Pennsylvania Turnpike System, the small rotary drilling machines, using split spoons and diamond bit core barrels, obtained the most reliable data from each of the shallow earth surface conditions. These machines frequently located the top of sound rock, relative to a stable 3/4 to 1 cut slope, at casing refusal when driven with a 250 to 300 lb. hammer free falling about thirty inches. However, if subsequent core boring, with a single tube core barrel, yielded a core recovery approximately less than 50 per cent, the top of sound rock was found

to be at a point where core recovery became greater than approximately 50 per cent.

In soft homogeneous gradationally weathered rock formations, the continuous flight power auger with a rock cutter-head furnished better slope design data and excavation data than did the electrical resistivity. In this material auger refusal marked a significant point. Above this point, the material was usually loose enough so that it could be treated as soil slope, and below the point the slope could be expected to stand at 3/4 to 1 or steeper. Also, below auger refusal, blasting might be anticipated for rock excavation. Auger and resistivity results were excellent where the contact of soil and rock was relatively sharp. Where the overburden extended below grade, both machines again gave excellent results. In boulder areas or areas of interbedded hard and very soft materials, it was necessary to depend more on the rotary core drilling rigs.

Since the small power auger was found to be so effective on this particular job, the writers feel that their greater use should be urged. It also is felt that industry should build a power auger designed specifically for subsurface exploration as encountered in civil engineering work. The greater percentage of exploration work can be done by a light and compact unit. It should be able to operate single flight, continuous flight and continuous flight hollow stem augers. It should be equipped with drop hammers to take various drive samples and with hydraulic apparatus for the smooth pushing of thin-walled sample tubes or the operating of a vane shear tester. No wash water equipment should be included as this makes the machine similar to the larger, more powerful, and more versatile rotary core drilling machines.

BIBLIOGRAPHY

1. Lobeck, A. K., Map, "Physiographic Provinces of North America," The Geographical Press, Columbia University, New York, 1958.

2. Terzaghi, K. and Peck, R. B., "Soil Mechanics in Engineering Practice," J. Wiley and Sons, Inc., New York, N. Y., 1948.

3. Hvorslev, M. J., "Subsurface Exploration and Sampling of Soils for Civil Engineering Purposes," U. S. Waterways Experiment Station, Vicksburg, Mississippi, 1949.

4. Shurig, D. G., "Power Augers and Earth Resistivity Units as Supplements to Drilling Machines," Thesis, Purdue University, 1957.